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(54) **OPTICAL ENCODER WITH AXIALLY ALIGNED SENSOR**

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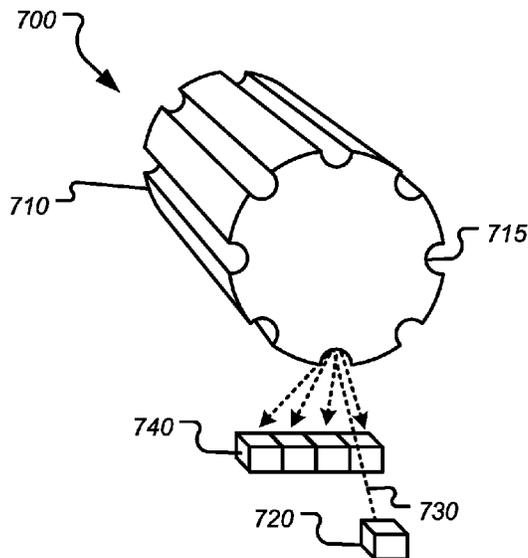
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(57) **ABSTRACT**

Embodiments of the present disclosure provide an optical encoder for an electronic device. The optical encoder comprises an elongated shaft and a plurality of markings axially disposed around a circumference of the elongated shaft. The optical encoder also includes an optical sensor. In embodiments, the optical sensor includes an emitter and an array of photodiodes. The emitter and the array of photodiodes may be radially aligned with respect to the elongated shaft or axially aligned with respect to the shaft.

**19 Claims, 7 Drawing Sheets**



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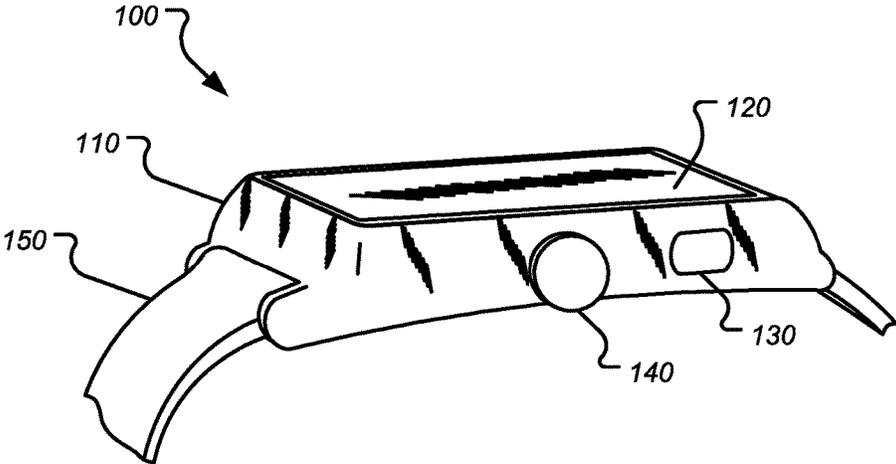
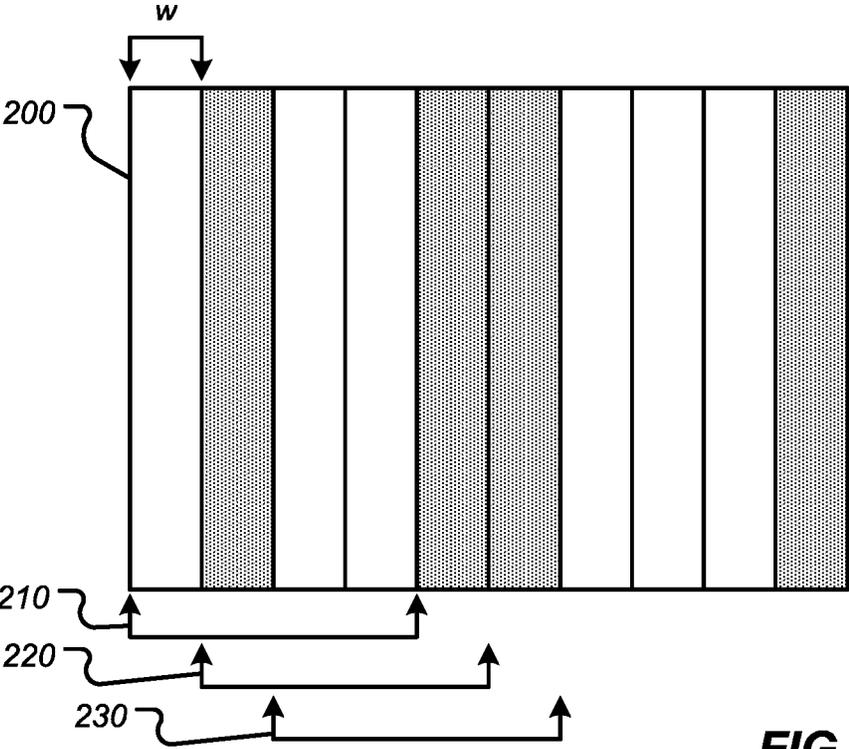


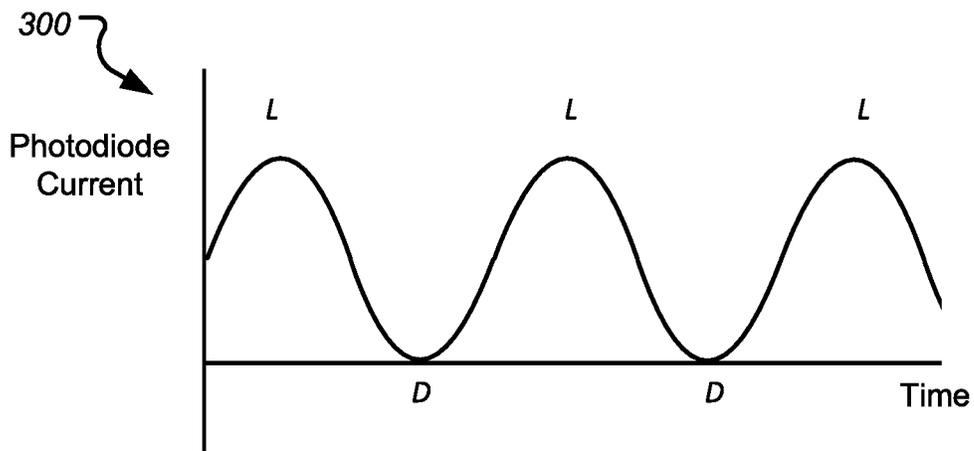
FIG. 1A



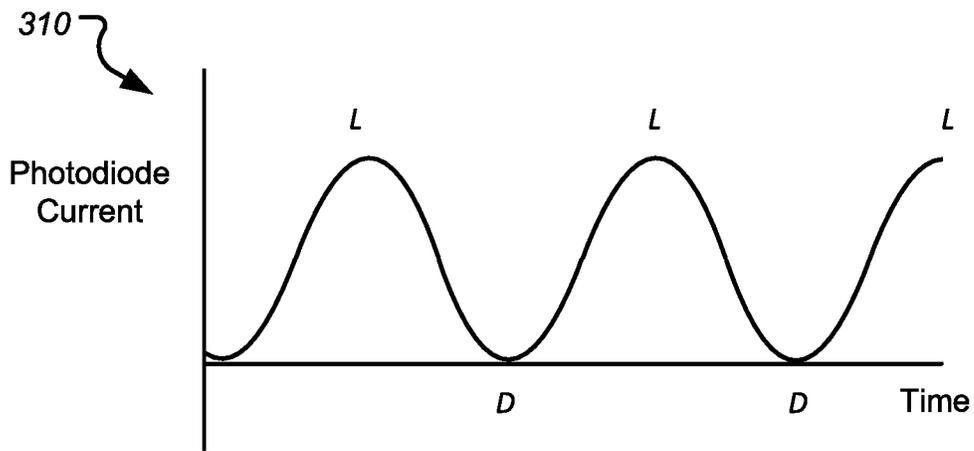
FIG. 1B



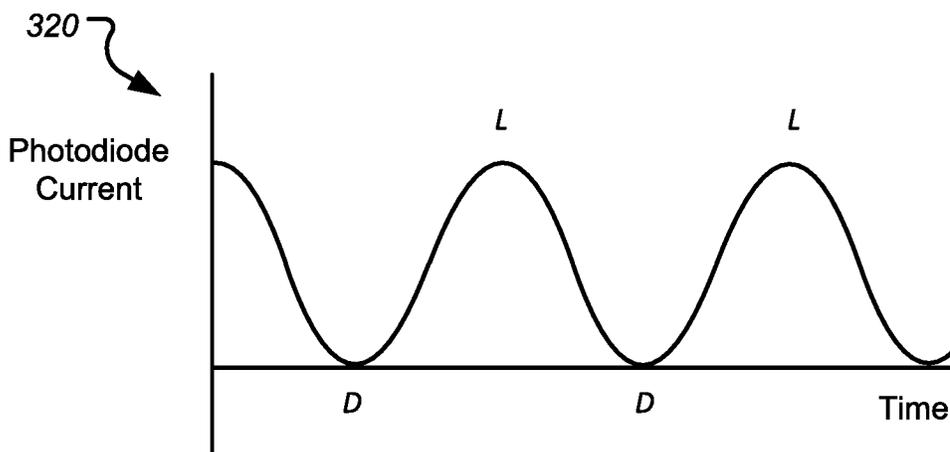
**FIG. 2**



**FIG. 3A**



**FIG. 3B**



**FIG. 3C**

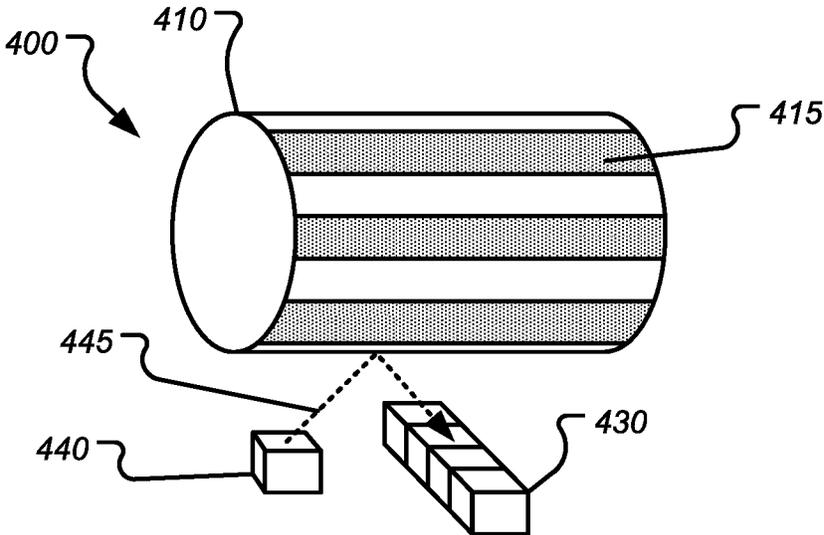


FIG. 4A

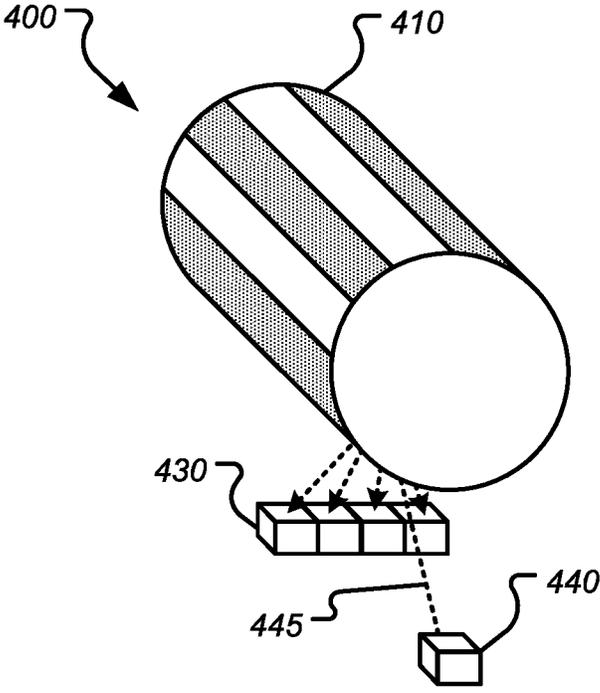
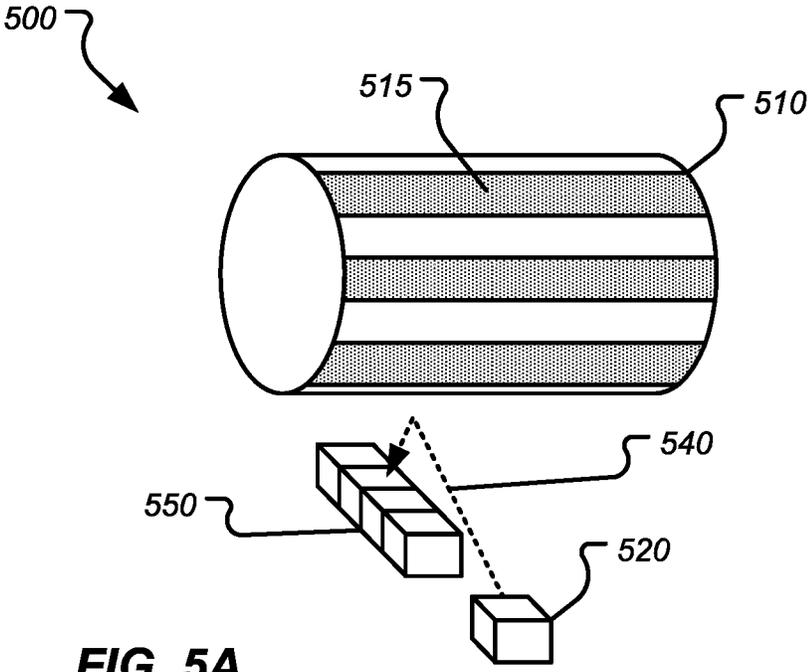
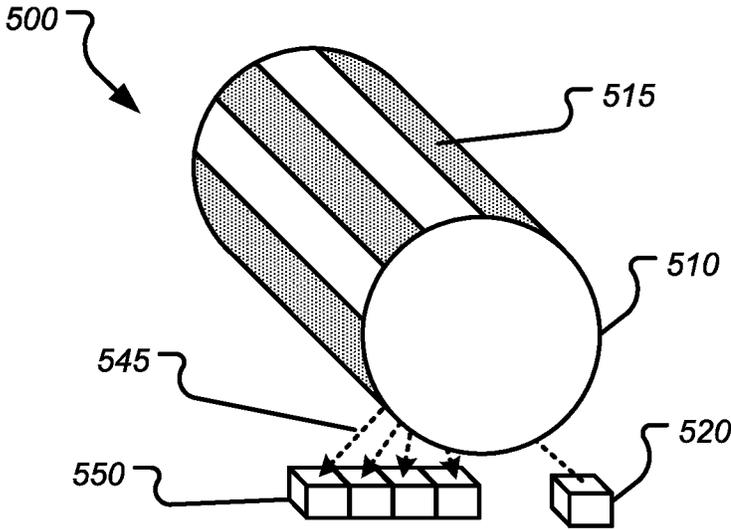


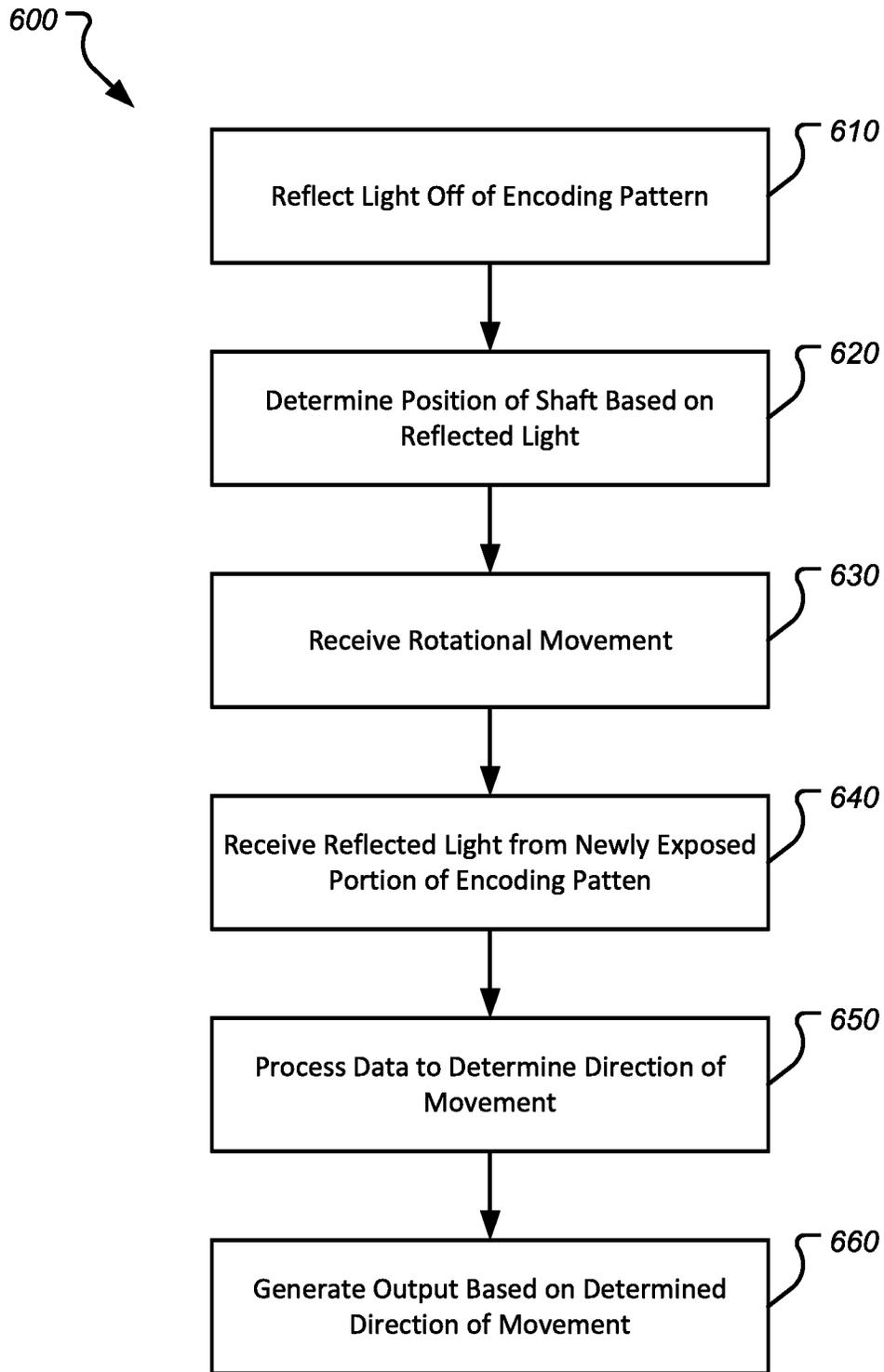
FIG. 4B



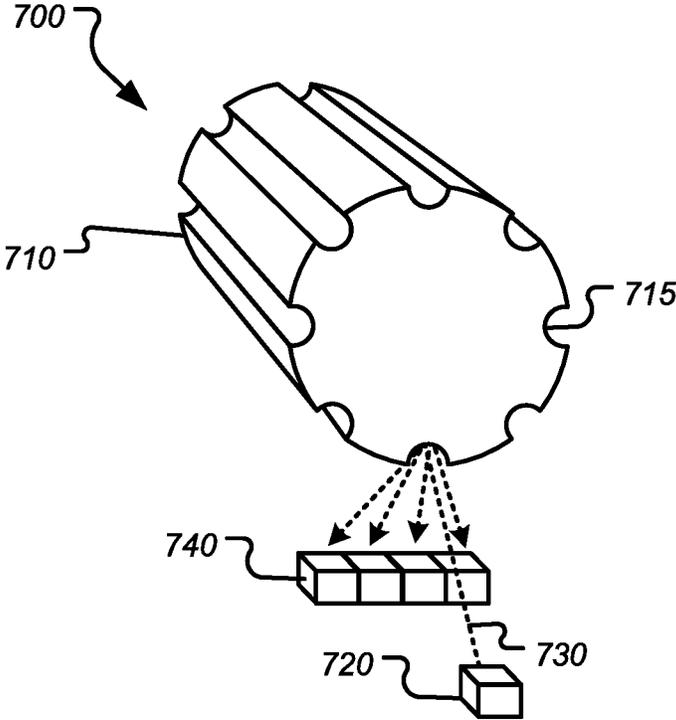
**FIG. 5A**



**FIG. 5B**



**FIG. 6**



**FIG. 7**

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## OPTICAL ENCODER WITH AXIALLY ALIGNED SENSOR

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. Nonprovisional patent application Ser. No. 14/333,418, filed Jul. 16, 2014, the disclosures of which are hereby incorporated herein by reference in their entirety.

### TECHNICAL FIELD

The present disclosure is directed to optical encoders for electronic devices. Specifically, the present disclosure is directed to an optical encoder in which markings of an encoding pattern of the optical encoder has an axial component disposed around a circumference of the shaft of the optical encoder. In addition, a light source and a photodiode array are axially or radially aligned with respect to the optical encoder so as to detect the rotational or linear movement of the shaft of the optical encoder.

### BACKGROUND

Many devices, including mechanical, electronic and computerized devices, may utilize various types of encoders for obtaining and collecting data about the particular device. For example, a rotary encoder may be used to collect information about a position of a component in the device, a direction in which the component is moving, and/or a speed of the movement of the component. However, some of these encoders are not suitable for use in a small or compact space that may be required for an electronic device having a small form factor.

It is with respect to these and other general considerations that embodiments have been made. Also, although relatively specific problems have been discussed, it should be understood that the embodiments should not be limited to solving the specific problems identified in the background.

### SUMMARY

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description section. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

Embodiments of the present disclosure provide an optical encoder for an electronic device. The optical encoder comprises an elongated shaft having an axial component. The axial component may consist of a plurality of stripes or markings that are axially disposed around a circumference of the elongated shaft. The optical encoder also includes an optical sensor. In embodiments, the optical sensor includes an emitter and a photodiode array. The emitter and the photodiode array may be radially aligned with respect to the elongated shaft or axially aligned with respect to the elongated shaft.

In another embodiment, an electronic device is provided. The electronic device includes a processor, a memory and an optical encoder. The optical encoder comprises an elongated shaft having a plurality of markings axially disposed around a circumference. The optical encoder may also include a light source and a photodiode array. The light source and the

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photodiode array may be radially aligned with respect to the elongated shaft or axially aligned with respect to the elongated shaft.

In another embodiment of the present disclosure, a method for detecting rotational movement of a shaft contained within a housing of an electronic device is disclosed. In these embodiments, a light source is configured to emanate light on the shaft. The shaft includes a plurality of markings or stripes that are axially disposed around a circumference of the shaft. The markings or stripes disposed on the shaft are configured to reflect the light into a plurality of photodiodes. When the reflected light is received by the plurality of photodiodes, rotational movement and directional movement of the shaft may be determined.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A illustrates an exemplary electronic device according to one or more embodiments of the present disclosure;

FIG. 1B illustrates a cross-sectional view of the electronic device of FIG. 1A according to one or more embodiments of the present disclosure;

FIG. 2 illustrates an exemplary encoding pattern of an optical encoder according to embodiments of the present disclosure;

FIGS. 3A-3C illustrate exemplary current output graphs of a photodiode array according to embodiments of the present disclosure;

FIGS. 4A-4B illustrate an optical encoder having components of an optical sensor axially aligned with respect to the shaft of the optical encoder according to one or more embodiments of the present disclosure;

FIGS. 5A-5B illustrate an optical encoder having components of an optical sensor radially aligned with respect to the shaft of the optical encoder according to one or more embodiments of the present disclosure;

FIG. 6 illustrates a method for detecting movement of a component of an electronic device according to one or more embodiments of the present disclosure; and

FIG. 7 illustrates an optical encoder having a plurality of surface structures according to one or more embodiments of the present disclosure.

### DETAILED DESCRIPTION

Various embodiments are described more fully below with reference to the accompanying drawings, which form a part hereof, and which show specific exemplary embodiments. However, embodiments may be implemented in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the embodiments to those skilled in the art. The following detailed description is, therefore, not to be taken in a limiting sense.

In various electronic devices, rotational movement of a component of the electronic device may need to be determined. In such instances an optical encoder may be used to detect the rotational movement. More specifically, embodiments of the present disclosure use an optical encoder to detect rotational movement, rotational direction and/or rotational speed of a component of the electronic device. Once the rotational movement, rotational direction and/or rotational speed have been determined, this information may be

used to output or change information and images that are presented on a display or user interface of the electronic device.

As will be explained below, the optical encoder of the present disclosure includes a light source, a photodiode array, and a shaft. However, unlike typical optical encoders, the optical encoder of the present disclosure utilizes an encoding pattern disposed directly on the shaft. For example, the encoding pattern includes a number of light and dark markings or stripes that are axially disposed along the shaft. Each stripe or combination of stripes on the shaft may be used to identify a position of the shaft.

For example, as light is emitted from the light source and reflected off of the shaft into the photodiode array, a position, rotation, rotation direction and rotation speed of the shaft may be determined. Once the rotation direction and speed are determined, this information may be used to output or change information or images that are presented on the display or user interface of the electronic device.

In other embodiments, the shape or form of the shaft of the encoder may be used to determine a position, rotation, rotation direction and rotation speed of the shaft. For example, the shaft may be fluted or have a number of channels that cause the light to be reflected in a number of different directions. Accordingly, a diffractive pattern may be used to determine the rotation, rotation direction and rotation speed of the shaft.

FIG. 1A illustrates an exemplary electronic device **100** according to one or more embodiments of the present disclosure. In certain embodiments, the electronic device **100** may be a portable computing device. Such examples include cell phones, smart phones, tablet computers, laptop computers, time-keeping devices, computerized glasses and other wearable devices navigation devices, sports devices, accessory devices, health-monitoring devices, medical devices and the like. In one example and as shown in FIG. 1, the electronic device **100** may be a wearable electronic device. The electronic device **100** may include a housing **110** as well as a display **120**, a button **130** (or other input mechanism) and a crown **140**.

In many examples, the wearable device, such as is depicted in FIG. 1A, may include a processor coupled with or in communication with a memory, one or more communication interfaces, output devices such as displays and speakers, and one or more additional input devices such as buttons, dials, microphones, or touch-based interfaces. The communication interface(s) can provide electronic communications between the communications device and any external communication network, device or platform, such as but not limited to wireless interfaces, Bluetooth interfaces, Near Field Communication interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces. The wearable electronic device **100** may provide information regarding time, health, statuses or externally connected or communicating devices and/or software executing on such devices, messages, video, operating commands, and so forth (and may receive any of the foregoing from an external device), in addition to communications.

In embodiments, the display **120** of the electronic device **100** may be a touch-sensitive display having an input area. The input area may cover the entire display **120** or substantially all of the display **120**. In another embodiment, the input area may cover only a portion of the display **120**.

The display **120** is configured to output a user interface that displays information about the electronic device **100** as well as other information that is stored in a memory of the

electronic device **100**. For example, the user interface may present information corresponding to one or more applications that are being executed on the electronic device **100**. Such applications may include a time keeping application, an email application, a phone application, a calendaring application, a game application and the like.

In embodiments, the button **130** or the crown **140** may be used to select, adjust or change various images that are output on the display **120**. For example, if the display **120** of the electronic device **100** is displaying a time keeping application, the crown **140** may be rotated in either direction to change or adjust the position of the hands or the digits that are displayed for the time keeping application. In other embodiments, the crown **140** may be rotated to move a cursor or other type of selection mechanism from a first displayed location to a second displayed location in order to select an icon or move the selection mechanism between various icons that are output on the display **120**. Likewise, the crown may be pushed or pressed to provide another input to the device **100**.

Although not shown in FIG. 1A, the electronic device **100** may also include various additional components that assist in the overall operation of the device. For example, the electronic device **100** may include a sensor, a microphone, a processor, a memory, and the like. Further, the crown **140** and the button **130** may interact with one or more of the components listed to facilitate operation of the electronic device **100**.

The electronic device **100** may also include a band **150** that may be used to secure or attach the electronic device **100** to a user. Other attachment mechanisms, such as, for example, a strap, a lanyard or other such attachment mechanism may also be used.

In certain embodiments, electronic device **100** may also include a keyboard or other input mechanism. Additionally, the electronic device **100** may include one or more components that enable the electronic device **100** to connect to the Internet and/or access one or more remote databases or storage devices. The electronic device **100** may also enable communication over wireless media such as acoustic, radio frequency (RF), infrared, and other wireless media mediums. Such communication channels may enable the electronic device **100** to remotely connect and communicate with one or more additional devices such as, for example, a laptop computer, tablet computer, mobile telephone, personal digital assistant, portable music player, speakers and/or headphones and the like.

FIG. 1B illustrates a cross-sectional view of the electronic device **100** of FIG. 1A according to one or more embodiments of the present disclosure. As shown in FIG. 1B, the electronic device **100** includes an optical encoder that consists of a shaft **160**, a light source **170** and a photodiode array **180**. Although a photodiode array is specifically mentioned, embodiments disclosed herein may use various types of sensors that are arranged in various configurations for detecting the movement described herein. For example, the movement of the shaft **160** may be detected by an image sensor, a light sensor such as a CMOS light sensor or imager, a photovoltaic cell or system, photo resistive component, a laser scanner and the like.

In embodiments, and as will be discussed below, the optical encoder is used to determine positional data of the crown **140**. More specifically, the optical encoder may be used to detect that movement of the crown **140** including the direction of the movement, speed of the movement and so on. The movement may be rotational movement, translational movement, angular movement and so on. The optical

encoder may also be used to detect the degree of the change of rotation of the crown **140** and/or the angle of rotation of the crown **140** as well as the speed and the direction of the rotation of the crown **140**. Once the movement data of the crown **140** is determined, one or more graphics, images or icons on the display **120** of the electronic device **100** may be updated or altered accordingly.

For example, continuing with the time keeping application example discussed above, the crown **140** may be rotated in a clockwise manner in order to change the displayed time. The optical encoder of the present disclosure will detect the original starting position of the crown **140**, the rotational movement of the crown **140** in the clockwise direction, and will also detect the speed at which the crown **140** is being rotated. As a result, the displayed hands of the time keeping application may rotate or otherwise move in a similar direction and speed.

Referring back to FIG. 1B, the optical encoder may include a shaft **160**. The shaft **160** may be coupled to the crown **140**. In another embodiment the shaft **160** may be an extension of the crown **140**. That is, the crown **140** and the shaft **160** may be manufactured from a single piece. As the shaft **160** is coupled to, or is otherwise a part of the crown **140**, as the crown **140** rotates or moves in a particular direction and at a particular speed, the shaft **160** also rotates or moves in the same direction and with the same speed.

The shaft **160** of the optical encoder includes an encoding pattern **165**. As discussed, the encoding pattern **165** is used to determine positional information about the shaft **160** including rotational movement, angular displacement and movement speed. The encoding pattern **165** may include a plurality of light and dark stripes such as shown in FIG. 1B.

Although light stripes and dark stripes are specifically mentioned and shown, the encoding pattern may consist of various types of stripes having various shades or colors that provide surface contrasts. For example, the encoding pattern may include a stripe or marking that has a high reflective surface and another stripe that has a low reflective surface regardless of the color or shading of the stripes or markings. In another embodiment, a first stripe of the encoding pattern may cause specular reflection while a second stripe of the encoding pattern may cause diffuse reflection. When the reflected light is received by the photodiode array, a determination may be made as to the position and movement of the shaft such as described below. In embodiments where a holographic or diffractive pattern is used, the light from the light source will diffract from the shaft. Based on the diffracted light, the photodiode array may determine the position, movement and direction of movement of the shaft.

In embodiments, the stripes of the encoding pattern **165** extend axially along the shaft **160**. The stripes may extend along the entire length of the shaft **160** or partially along a length of the shaft. In addition, the encoding pattern **165** may also be disposed around the entire circumference of the shaft **160**. In other embodiments, the encoding pattern may include a radial component. In yet other embodiments, the encoding pattern may have both a radial component and an axial component.

In another embodiment, the encoding pattern **165** may be disposed only on certain areas of the shaft **160**. For example, if a shaft **160** was configured to have partial rotational movement about an axis in a given direction (instead of full rotational movement about the axis such as described herein), the encoding pattern **165** may only be disposed on a portion of the shaft **160** that would be visible to the photodiode array **180** as the shaft **160** is rotated.

The light and dark stripes of the encoding pattern **165** may alternate between a light stripe and a dark stripe. In another embodiment, the light stripes and the dark stripes of the encoding pattern **165** may be arranged in a particular pattern or order. In such embodiments, each section of the pattern may indicate a position of the shaft **160**.

For example, as shown in FIG. 2, the stripes of an exemplary encoding pattern **200** disposed on a shaft of an optical encoder may be arranged as follows: light, dark, light, light, dark, dark, light, light, light, dark. Further, four stripes in combination may represent a four bit pattern that is associated with a position of the shaft.

Specifically, in the example shown in FIG. 2, the pattern **210** consists of stripes in the following order: light, dark, light, light. Likewise, the pattern **220** consists of stripes in the following order: dark, light, light, dark. Further, the pattern **230** consists of the following stripes: light, light, dark, dark and so on. Because there are no repeating patterns in the encoding pattern **200**, each pattern (e.g., patterns **210**, **220** and **230**) would indicate a rotational position of the shaft of the encoder. As such, as the photodiode array detects the change in the pattern, movement of the shaft, including the direction of the movement and the speed of the movement, may be determined.

For example, if the photodiode array determines that pattern **220** is viewable at a first time and subsequently views pattern **210**, a determination may be made that the shaft is moving in a counter-clockwise direction. Likewise, if the photodiode array determines that pattern **220** is viewable at a first time and subsequently views pattern **230**, a determination may be made that the shaft is moving in a clockwise direction.

Although FIG. 2 illustrates an encoding pattern **200** in which the stripes themselves are arranged in a particular order, the stripes of the encoding pattern may alternate between a light stripe and a dark stripe. In other embodiments, the shading or color of each stripe may vary.

As also shown in FIG. 2, each stripe of the encoding pattern **200** may have a width  $w$ . In some embodiments, the width  $w$  of each of the stripes on the encoding pattern **200** may be uniform or substantially uniform. Accordingly, in embodiments where the stripes are arranged as alternating light and dark stripes, the uniformity of the stripes of the encoding pattern **200** may enable a measurement of rotation of the shaft.

In another embodiment, the stripes may indicate a starting position of a shaft of an encoder. As the shaft rotates, a number of revolutions of the shaft may be calculated and stored by the computing device **100** to determine a new rotational position of the shaft.

In another embodiment, the width  $w$  of each stripe of the encoding pattern **200** may vary. For example, each of the light stripes of the encoding pattern **200** may have a first width while each of the dark markings of the encoding pattern **200** may have a second, different width. In another example, a first stripe of the encoding pattern **200** may have a first width, a second stripe of the encoding pattern **200** may have a second width, and a third stripe of the encoding pattern **200** may have a third width. Such an arrangement may enable a computing device, such as, for example, computing device **100** to measure a position of the shaft based on the various widths of the stripes. The variable width of each of the stripes may be used in any of the encoding patterns discussed herein. For example, stripes having variable widths may be used in encoding patterns in which the order of the stripes vary, such as shown in FIG. 2,

or in embodiments where the stripes of the encoding pattern alternate between light and dark stripes.

In another example, the varying widths of the stripe may provide a pattern that indicates a position of the shaft **160**. For example, a stripe having a first width may indicate that the shaft **160** is in a first position while a stripe having a second width may indicate the shaft **160** is in a second position. In still yet another example, the different widths of each of the strips may be used to determine linear movement of the shaft **160** as well as rotational movement of the shaft **160**.

The stripes of the encoding pattern **200** may also be arranged in different patterns. For example, the stripes of the encoding pattern **200** may be arranged in a QR code, a bar code or other such pattern that may be used to determine a rotational, translational, or angular movement of the shaft **160** as well as the movement speed of the shaft **160**.

Referring back to FIG. 1, the optical encoder of the present disclosure also includes a photodiode array **180**. The photodiode array **180** is configured to receive light that is reflected off of the shaft **160**. Specifically, the photodiode array **180** is configured to receive light of different intensity values based on whether the light has been reflected off of the encoding pattern and in a direction toward to photodiode array in a diffusive manner, in a specular manner or a combination thereof.

For example, the photodiode array **180** may receive light that is reflected off of the encoding pattern **165**. Specifically, as light from the light source **170** hits the various stripes of the encoding pattern **165**, the light is reflected off of the light stripes in a specular manner and is reflected off of the dark stripes in a diffusive manner. The various intensities of the reflected light is then received by the photodiode array **180** which then converts the reflected light into an output current.

Thus, the higher the output current from the photodiode, the more the light stripe, or the reflective stripe, is seen by the photodiode array **180** (or seen by a particular photodiode of the photodiode array **180**). Likewise, the smaller the output current, the more the dark stripe, or non-reflective surface, is seen by the photodiode array **180** (or seen by a particular photodiode of the photodiode array **180**).

Based on the above, rotational information of the shaft **160**, and ultimately the crown **140** may be determined. For example, rotational data may be derived from analyzing the outputs of the photodiodes in the photodiode array **180** across various sample frames. The variance of the outputs in a given time between the sample frames is related to the motion or rotational direction of the stripes of the encoding pattern **165** and ultimately the shaft **160**.

Referring to FIGS. 3A-3C, FIGS. 3A-3C show exemplary current output graphs provided by a photodiode array. For example, each graph **300**, **310**, and **320** represent output provided by a photodiode array as it receives light that is reflected off of an encoding pattern. As discussed above, the sensor that is used to detect movement of the shaft of the optical encoder may be any type of sensor. Thus, the outputs shown in FIGS. 3A-3C are but one example of output provided by a sensor.

For example, the graph **300** shown in FIG. 3A may represent output of a photodiode array over a time  $t$ . In a subsequent time period, the output of the photodiode array may look like the output provided by graph **310** of FIG. 3B. When compared with the output of the graph **300** of FIG. 3A, it can be determined that the shaft of the encoder is rotating in a particular direction, such as, for example a clockwise direction. Similarly, when the output of graph **320** shown in FIG. 3C is compared with the output of graph **300**,

it can be determined that the shaft of the encoder is rotating in another direction such as, for example, a counter-clockwise rotation. More specifically, as the photodiodes in the photodiode array take multiple sequential samples and compare the samples with at least one previous sample, rotational direction is able to be determined based on the current output of the photodiode array.

In addition to the rotational information, the current output from the photodiode array may be used to determine a speed at which the shaft is rotating. In embodiments, the speed of the rotation of the shaft is determined based on how quickly the pattern of reflected light changes. Once the rotational direction and speed are determined, output on the display **120** may be adjusted accordingly. In addition, the output provided by the photodiode array may be used to detect the angular rotation of the shaft in a similar manner.

Although the examples above have been given with respect to rotational movement, the embodiments described herein may also be used to detect linear or translational movement of the shaft **160**. For example, a user may push the crown **140** toward the housing **110** or pull the crown **140** away from the housing **110**. In such embodiments, the light that is reflected off of the encoding pattern **165** and received by the photodiode array **180** may be used to determine the above-described translational movement of the shaft **160**.

Referring back to FIG. 1B, the light source **170** of the electronic device **100** may be any type of emitter that provides a light that can be reflected off of the shaft **160** to be received by the photodiode array **180**. For example, the light source **170** may be an LED, an infrared light such as, for example an infrared LED, a laser diode, a light bulb and the like.

In embodiments when the light source **170** is an infrared light source, the encoding pattern **165** disposed on the shaft **160** may be invisible to the human eye but the overall movement determination may operate as described above. For example, a first set of stripes of the encoding pattern **165** may be IR-absorptive and a second set of stripes of the encoding pattern **165** may be IR-reflective. The photodiode array may receive the IR-reflective light when the IR-reflective stripe is shown and less light as the shaft turns. Accordingly, a determination of rotational movement may be made as described above.

In embodiments, the light source **170** and the photodiode array **180** are axially aligned with respect to the shaft **160**. In another embodiment, the light source **170** and the photodiode array **180** may be radially aligned with respect to the shaft **160**. Although specific alignments are disclosed, in certain embodiments the light source **170** and the photodiode array **180** may be aligned with the shaft **160** in any suitable manner so long as light is emitted from the light source **170** is reflected off of the encoding pattern **165** on the shaft **160** and received by the photodiode array **180**.

Depending on the use of the shaft **160**, the length of the shaft **160** may vary between embodiments. For example, in some embodiments, the length of the shaft **160** may extend along a length or width of the housing **110**. In another embodiment, the shaft **160** may have a length that is substantially less than a length or width of the housing **110**.

In addition to the above, the distance in a  $z$  direction between the shaft **160** and the light source **170** and the photodiode array **180** may also vary. Generally, it should be noted that, as the  $z$  distance between the shaft **160** and the light source **170** and the photodiode array **180** increases, the pattern of light reflected off of the shaft **160** increases in size. Specifically, the number of samples in a given time frame decreases. Likewise, as the  $z$  distance between the shaft **160**

and the light source 170 and the photodiode array 180 decreases, the pattern of light reflected off of the shaft 160 decreases in size. More specifically, the number of samples in a given time frame increases. As the number of samples increase, the rotational direction and the rotation speed of the shaft may be better determined.

FIGS. 4A-4B illustrate an optical encoder 400 having components of an optical sensor axially aligned with respect to the shaft 410 of the optical encoder 400 according to one or more embodiments of the present disclosure. In embodiments, the optical encoder 400 may be similar to the optical encoder shown and described with respect to FIG. 1A and FIG. 1B.

As shown in FIG. 4A, the optical encoder 400 includes a shaft 410, a light source 440 and a photodiode array 430. The shaft 410 includes an encoding pattern 415. The encoding pattern 415 may include a plurality of different colored stripes or shaded stripes. For example, a first stripe of the encoding pattern may be in a first color, a second stripe of the encoding pattern may be in a second color and a third stripe of the encoding pattern 415 may be in a third color. As different colors may be used, the photodiode array 550 may be color-sensitive. Accordingly the change in color in the encoding pattern 515 as the shaft rotates about its axis may be used to determine rotational movement and speed of the shaft 510.

In addition, the stripes of the encoding pattern 415 are axially aligned with respect to the shaft 410. In addition, the stripes of the encoding pattern are arranged circumferentially around the shaft 410.

In certain embodiments, the stripes of the encoding pattern 415 may be configured to cause specular reflection and diffuse reflection. For example, as shown in FIG. 4A, the light 445 from the light source 440 may be reflected in a specular manner from the shaft to the photodiode array 430. In the example shown in FIG. 4B, the light 445 from the light source is diffusively reflected from the shaft 410 to the photodiode array 430.

Although embodiments shown and described discuss the use of both light and dark stripes in the encoding pattern, in certain embodiments, the entire shaft 410 may be specular (e.g., the entire shaft 410 enables specular reflection). In such embodiments, the shaft 410 may have one or more striations, flutes, channels and the like.

For example, as shown in FIG. 7, a shaft 710 of an optical encoder 700 may include a plurality of surface forms 715, such as, for example one or more flutes, channels and the like. The surface forms 715 may be axially aligned with respect to the shaft 710, radially aligned with respect to the shaft 710 or a combination thereof. These surface forms may cause light to be reflected from the shaft 710 even if there is no variation in color or reflectance from the shaft 710. In embodiments, the surface forms 715 may be added to the shaft 710 during the manufacturing process or may be a natural byproduct (or otherwise present) in the shaft 710 due to a machining process.

In embodiments where the surface forms 715 are present, the shape of the one or more surface forms 715 in the shaft 710 may cause the light 730 from a light source 720 to be reflected from the shaft 710 in many different angles and be received by a photodiode array 740, thereby undergoing diffuse reflection. In such embodiments, the surface forms may vary in size or have the same or substantially the same size. In other embodiments, the shaft 710 may include surface forms 715 as well as one or more light and/or dark stripes of an encoding pattern such as described above. As

such, both features may then be used in conjunction to determine rotational and/or linear movement and speed such as described above.

Referring back to FIG. 4A, the optical encoder 400 may include a light source 440 and a photodiode array 430. In embodiments, the light source 440 is axially aligned with the photodiode array 430 as a whole. Further, the light source 440 is axially aligned with an axis of rotation of the shaft 410.

Axial alignment of the light source 440 and photodiode array 430 in the manner specified may require that the shaft 410 be longer than the embodiments shown and described in FIG. 5A and FIG. 5B to enable the light from the light source to be reflected off the shaft 410 and received by the photodiode array 430. Although the length of the shaft may be increased, axial alignment of the light source 440 and the photodiode array 430 may enable more accurate rotation data to be received as the light 445 is reflected off of the shaft 410 and collected by the photodiode array 430.

Although four photodiodes are specifically shown and described in the photodiode array 430, any number of photodiodes may be used. The number of photodiodes may increase or decrease depending on the size of the collection area of each of the photodiodes. For example, an accurate rotational or linear movement of the shaft 410 may be collected from an array of two photodiodes. In other embodiments, eight or more photodiodes may be required. In another embodiment, multiple arrays of photodiodes may be used. Further, each of photodiode arrays may be arranged in various alignments and positions with respect to the shaft 410.

FIGS. 5A-5B illustrate an optical encoder 500 having components of an optical sensor radially aligned with respect to the shaft 510 of the optical encoder according to one or more embodiments of the present disclosure. In embodiments, the optical encoder 500 may be similar to the optical encoder 100 shown and described with respect to FIG. 1A and FIG. 1B.

As shown in FIG. 5A, the optical encoder 500 includes a shaft 510, a light source 520 and a photodiode array 550. The shaft 510 includes an encoding pattern 515. The encoding pattern 515 may include a plurality of different colored stripes or shaded stripes. For example, a first stripe of the encoding pattern may be in a first color, a second stripe of the encoding pattern may be in a second color and a third stripe of the encoding pattern 515 may be in a third color. As different colors may be used, the photodiode array 550 may be color-sensitive. Accordingly the change in color in the encoding pattern 515 as the shaft rotates about its axis may be used to determine rotational movement and speed of the shaft 510.

Referring back to FIG. 5A, in certain embodiments, the stripes of the encoding pattern 515 are axially aligned with respect to the shaft 510. In addition, the markings of the encoding pattern 515 are arranged around a circumference of the shaft 510.

As discussed above, the markings of the encoding pattern 515 may be configured to cause specular reflection and diffuse reflection. For example, as shown in FIG. 5A, the light 540 from the light source 520 may be reflected in a specular manner from the shaft to the photodiode array 550. In the example shown in FIG. 5B, the light 545 from the light source 520 is diffusively reflected from the shaft 510 to the photodiode 550.

In certain embodiments, the entire shaft 510 may be coated with a coating or a marking that enables specular

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reflection. In such embodiments, the shaft **510** may have one or more surface structures such as shown and described with respect to FIG. 7.

As also shown in FIG. 5A, the optical encoder **500** may include a light source **520** and a photodiode array **550**. In 5  
embodiments, the light source **520** and the photodiode array **550** are radially aligned with respect to the shaft **510**. The radial alignment of the light source **520** and photodiode array **540** may enable the shaft **510** to be shorter than the embodiments shown in FIG. 4A and FIG. 4B.

In embodiments and as shown in FIG. 5A and FIG. 5B, the photodiode array **550** may include four photodiodes. Although four photodiodes are specifically shown and described, any number of photodiodes may be used for the array **550**. For example, the number of photodiodes may increase or decrease depending on the size of the collection area of each of the photodiodes such as described above

FIG. 6 illustrates a method **600** for collecting and determining movement of a shaft of an optical encoder according to one or more embodiments of the present disclosure. In 10  
embodiments, the method **600** may be used to determine rotational movement of the shaft, angular movement of the shaft, translational movement of the shaft as well as a speed of movement of the shaft. Further, the method **600** described below may be used with the embodiments shown and described above with respect to FIG. 1A through FIG. 5B.

The method **600** begins by causing light from a light source to be reflected off of an encoding pattern that is disposed on a shaft of an optical encoder. The encoding pattern disposed on the shaft may include a plurality of light and dark stripes that are axially disposed along a length of the shaft of the optical encoder such as described above.

In another embodiment, the shaft of the optical encoder may include one or more surface components such as shown in FIG. 7. In such embodiments, the surface components 15  
may be used to reflect light in a variety of different directions. The surface components may be used in conjunction with the light and dark markings of the encoding pattern. In alternative embodiments, the surface components may be used without the need of either one or both of the light markings of the encoding pattern or the dark markings of the encoding pattern.

In operation **620**, the light that is reflected off of the encoding pattern is received by a photodiode array. As discussed above, both the light source and the photodiode array may be axially aligned with the shaft. In another embodiment, both the light source and the photodiode array are radially aligned with respect to the shaft. Although axial alignment and radial alignment are specifically mentioned, other alignments may be used.

When the photodiode array receives the reflected light, an initial position of the shaft may be determined. Specifically, as light is reflected from the encoding pattern and received by the photodiode array, the photodiode array outputs a current which represents the amount of light and dark stripes that are in view of the photodiode array. This output current may then be used to represent a position of the shaft at a time t.

Flow then proceeds to operation **630** in which movement of the shaft is received. In embodiment, the movement may be rotational movement, translational movement, angular movement or combinations thereof. For example a crown of an electronic device may be rotated to change an output on a display such as described above. In another embodiment, the crown may be pushed inward or pulled outward.

Flow then proceeds to operation **640** in which light from the newly exposed portion of the encoding pattern is

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received by the array of photodiodes. When the newly reflected light is received, the photodiode array outputs a current based on the intensity of the reflected light.

Once the reflected light from the newly exposed encoding pattern is received, operation **650** provides that the data output by the photodiode array is analyzed to determine a direction of movement of the shaft. In embodiments, the speed of the movement of the shaft may also be determined.

Specifically, operation **650** provides that data output by the photodiode array from operation **620** above may be compared against data output by the photodiode array from operation **640**. For example, light intensity received by the photodiode array at a first time is compared against light intensity received by the photodiode at a second time. If the light intensity at the second time is greater than the light intensity at the first time, the shaft may be rotating in a counter-clockwise direction. Likewise, if the light intensity at the second time is less than light intensity at a first time, the shaft may be rotating in a clockwise rotation. Although the example above specifies that two samples are compared to determine movement of the shaft, operation **650** may use any number of samples, sequential or otherwise, to determine a directional movement of the shaft of the encoder.

Further, operation **650** may be used to determine a speed of rotation of the shaft. For example, as the photodiode array outputs the detected change in current, the speed of the change may also be monitored. The change in speed may then be used to determine the overall speed of the movement of the shaft.

In operation **660**, output is generated based on the determined direction of the movement of the shaft. For example, as a crown of an electronic device is rotated or otherwise moves, one or more icons or images a display of the electronic device may need to be updated accordingly. For example, if the display of the electronic device is displaying a time keeping application, the crown of the electronic device may be rotated in either direction to change or adjust the position of the hands that are displayed by the time keeping application. Specifically, the hands that are displayed by the time keeping application may move in the direction and speed indicated by the determined movement and speed of the shaft such as described above.

Although embodiments have been described above with respect to a rotational and translational movement of a shaft of an electronic device, embodiments of the present disclosure are not so limited. For example, the crown of the electronic device shown with respect to FIG. 1A could be replaced by a keycap for a keyboard. Thus, each key of the keyboard may be optically encoded for translational movement or other types of movement. In other embodiments, the optical encoder disclosed herein could be used with a button a sliding switch and the like.

Embodiments of the present disclosure are described above with reference to block diagrams and operational illustrations of methods and the like. The operations described may occur out of the order as shown in any of the figures. Additionally, one or more operations may be removed or executed substantially concurrently. For example, two blocks shown in succession may be executed substantially concurrently. Additionally, the blocks may be executed in the reverse order.

The description and illustration of one or more embodiments provided in this disclosure are not intended to limit or restrict the scope of the present disclosure as claimed. The embodiments, examples, and details provided in this disclosure are considered sufficient to convey possession and enable others to make and use the best mode of the claimed

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embodiments. Additionally, the claimed embodiments should not be construed as being limited to any embodiment, example, or detail provided above. Regardless of whether shown and described in combination or separately, the various features, including structural features and method-  
 5 ological features, are intended to be selectively included or omitted to produce an embodiment with a particular set of features. Having been provided with the description and illustration of the present application, one skilled in the art may envision variations, modifications, and alternate  
 10 embodiments falling within the spirit of the broader aspects of the embodiments described herein that do not depart from the broader scope of the claimed embodiments.

We claim:

1. An optical encoder for an electronic device, the optical  
 15 encoder comprising:

a processor;  
 an elongated shaft;

a plurality of rotationally asymmetric surface forms of  
 20 different sizes disposed around a circumference of the elongated shaft; and

an optical sensor comprising a light emitter and a plurality  
 of photodiodes;

wherein:

the optical sensor is axially aligned with respect to the  
 25 elongated shaft;

the plurality of photodiodes are configured to receive light  
 emitted from the light emitter and reflected from the  
 surface forms;

the processor is communicatively linked with the plurality  
 30 of photodiodes; and

the processor is configured to determine a rotation of the  
 elongated shaft using an output of the plurality of  
 photodiodes.

2. The optical encoder of claim 1, wherein the plurality of  
 35 photodiodes is configured in an array that has a dimension that is aligned radially with respect to the elongated shaft.

3. The optical encoder of claim 2, wherein the surface  
 forms reflect the emitted light at least partially along the  
 40 dimension of the array of photodiodes that is radially aligned.

4. The optical encoder of claim 1, wherein the light  
 emitter is a light emitting diode.

5. The optical encoder of claim 1, wherein the surface  
 forms comprise channels in the elongated shaft.

6. The optical encoder of claim 1, wherein the surface  
 forms form a diffraction pattern.

7. The optical encoder of claim 1, wherein the surface  
 forms reflect light toward the plurality of photodetectors at  
 50 different angles.

8. The optical encoder of claim 1, further comprising a  
 crown, wherein the crown is coupled to the elongated shaft.

9. An electronic device comprising:

a processor;

a memory;

an elongated shaft formed by a machining process and  
 55 having a plurality of rotationally asymmetric surface forms of different sizes formed as a byproduct of the machining process and disposed around a circumfer-  
 60 ence of the elongated shaft;

a light emitter configured to direct light axially onto the  
 elongated shaft; and

a light sensor comprising a plurality of photodiodes  
 positioned to receive light emitted from the light emit-  
 65 ter that has been reflected from the surface forms;

wherein:

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the light emitter and the light sensor are axially aligned  
 with respect to the elongated shaft;

the processor is communicatively linked with the light  
 sensor and the memory;

the elongated shaft is configured to rotate about its axis;  
 and

the processor is configured to determine a rotation of the  
 elongated shaft based on a signal from the light sensor.

10 10. The electronic device of claim 9, further comprising a crown coupled to an end of the elongated shaft and extending at least partially from a housing of the electronic device.

11. The electronic device of claim 9, wherein the plurality  
 15 of surface forms comprise axially oriented channels in the elongated shaft.

12. The electronic device of claim 9, wherein the surface  
 forms reflect the light in a plurality of directions.

13. The electronic device of claim 12, wherein the  
 20 reflected light has a diffraction pattern that is detected by the light sensor.

14. A method of detecting rotational movement of an  
 elongated shaft contained within a housing of an electronic  
 device, the method comprising:

causing a light source to emit light onto the elongated  
 shaft, wherein:

the elongated shaft includes a plurality of rotationally  
 asymmetric surface forms of different sizes disposed  
 around a circumference of the elongated shaft;

the emitted light is emitted axially with respect to the  
 elongated shaft; and

the surface forms cause the emitted light to reflect from  
 the elongated shaft;

receiving the reflected light at a plurality of photodiodes,  
 the plurality of photodiodes and the light source being  
 aligned axially with respect to the elongated shaft; and  
 35 determining a direction of the rotational movement of the elongated shaft based on the reflected light.

15. The method of claim 14, wherein determining a  
 direction of the rotational movement based on the reflected  
 light comprises comparing an output current of the plurality  
 of photodiodes at a first time period to an output current of  
 the plurality of photodiodes at a second time period.

16. The method of claim 14, further comprising deter-  
 45 mining a speed of rotational movement of the elongated shaft based on the reflected light.

17. The method of claim 16, further comprising altering  
 an operation of the electronic device based on at least one of  
 50 the direction and the speed of the rotational movement of the elongated shaft.

18. The method of claim 14, further comprising a machin-  
 ing process to form the elongated shaft, wherein the plurality  
 of surface forms are formed as a byproduct of the machining  
 process.

19. The electronic device of claim 13, wherein:  
 the elongated shaft has a first rotational position and a  
 second rotational position;

the reflected light has a first intensity at the first rotational  
 position and a second intensity at the second rotational  
 position; and

the processor, via the light sensor, determines a direction  
 of rotation of the elongated shaft by comparing the first  
 intensity and the second intensity.